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A ROTATING ELECTRIC MACHINE WITH A MAGNETIC CORE

The present invention relates to a rotating electric machine of the kind described in the preamble to claim 1.

The rotating electric machines which are referred to in this context comprises synchronous machines, which are substantially used as generators for connection to distribution and transmission networks, commonly called power networks. The synchronous machines are also used as motors as well as for phase compensation and voltage control, and, in that case, as mechanically idling machines. This technical field also comprises normal asynchronous machines, double-fed machines, AC-machines, asynchronous converter cascades, external pole machines and synchronous flux machines. These machines are intended to be used at high voltages, by which are meant here electric voltages which primarily exceed 10 kV. One typical field of operation for such a rotating machine may be 36 - 800 kV, and preferably 72.5 - 800 kV.

Rotating electric machines have conventionally been designed for voltages within the interval 6 - 30 kV, whereby 30 kV has normally been considered to be an upper limit. In the generator case, this normally implies that a generator must be connected to the power network over a transformer which steps up the voltage to the level of the network, which lies within the range of about 130 - 400 kV.

Over the years, various attempts have been made to develop special synchronous machines, preferably generators, for high voltages. Examples of this are described, inter alia, in "Electrical World", October 15, 1932, pages 524-525, the article "Water-and-Oil-cooled Turbogenerator TVM-300" in J. Elektrotechnika, No. 1, 1970, pages 6-8, and patent publications US 4,424,244 and SU 955 369. However, none of these attempts has been successful, nor have they resulted in any commercially available product.

However, it has proved to be possible to use as stator winding in a rotating electric machine high-voltage insulating electric conductors with solid insulation, of a similar design as cables for transmission of electric power (e.g. so-called XLPE cables). Such a cable has, inter alia, an outer semiconducting layer, through

which the outer potential of the cable is defined. In this way, the cable encloses the electric field inside the winding. In this way, the voltage of the machine may be increased to such levels that it may be directly connected to the power network without intermediate transformers. Thus, for example, the very important advantage is achieved that the conventional transformer may be eliminated.

The insulated conductor or high-voltage cable which is used in the present invention is, as mentioned, flexible and of the kind described in more detail in PCT applications SE97/00874 (WO 97/45919) and SE97/00875 (WO 97/45847). A further description of the insulated conductor or cable is to be found in PCT-applications SE97/00901 (WO 97/45918), SE97/00902 (WO 97/45930) and SE97/00903 (WO 97/45931).

The magnetic core in the machine normally consists of a stator surrounding the rotor of the machine. In such a machine, the winding through the core extends through axial slots in the stator. These slots are generally radially directed, which implies that the distance between the slots increases with the distance from the inner lateral area of the stator. This implies that the magnetic flux density decreases outwards in the stator. At the outer part of the slots, therefore, there is a surplus of core material, which normally consists of laminated sheet iron. This makes the machine unnecessarily bulky and heavy.

This latter is no major problem for small machines, but with increasing size of the machine, the problem is accentuated.

In accordance with the present invention, the winding is in the form of a conductor for high voltage, which implies that the machine becomes relatively large with a large number of winding parts in each slot. Designing a machine for high voltage has been made possible because the conductor according to the invention is provided with means for enclosing its electric fields, as indicated in the characterizing portion of claim 1.

The problem that a considerable part of the core material is superfluous and entails an unnecessary increase of the volume and weight of the machine is therefore of especially great importance in such a machine designed for high voltage.

In the light of the above facts, the object of the present invention is to achieve a machine which can directly supply/be supplied with high voltage and hence attempt to minimize the volume and weight of the machine.

According to the invention, this has been achieved by designing a machine, of the kind described in the preamble to claim 1, so as to comprise the special features which are described in the characterizing portion of the claim.

Because of the means enclosing the electric field, and which is described in the characterizing portion, a machine is achieved which may operate in the high-voltage range and thus be connected to a high-voltage network without being connected to an intermediate transformer.

Because the winding parts exhibit a displacement in relation to one another also in the circumferential direction, which is described as an additional important characterizing feature, the radial distance between two such parts of the winding may be reduced compared with a situation in which they are only radially displaced. If both winding parts are round and have the same diameter 2r and they are displaced, for example, by a distance r in relation to each other in the circumferential direction, there is room to reduce the radial distance between them by about 14%.

In the context of this application, the expression winding part means the extension of the cable between the axial ends of the stator core of one half-turn of the winding.

Another advantage is that the lateral displacement provides greater flexibility for the location of the parts of the winding in the core, which provides an increased possibility of optimizing the winding based on mechanical, magnetic, thermal and other aspects.

The winding parts in one and the same slot may thus be arranged to be more compact in relation to one another in the radial direction. This provides a possibility of reducing the extent of the slots in the radial direction such that the core may be made correspondingly smaller, with an ensuing lower weight. This results in saving of material and in advantages during manufacture and transport as well as during operation and maintenance.

The possibility of radially compacting the winding, permitted by the lateral displacement of the winding parts, of course becomes greater the more the space, which is made available by the lateral displacement, is utilized for radial compaction. According to a preferred embodiment of the invention, therefore, the pair of adjacently located winding parts is arranged such that the radially innermost portion of the outer winding part is located radially inside the outermost portion of the inner winding part.

In a preferred embodiment, the displacement increases the further out the winding parts are located. This implies that, during the compaction, the advantage is utilized that increasingly more space is available further out which is not claimed by core material and which may be utilized for increasing displacement in the circumferential direction and hence to reduce the volume to a corresponding extent.

In a preferred embodiment of the invention, the geometry of the slots is such that they also have a directional component in the transverse direction, which constitutes an appropriate adaptation of the shape of the slots to the laterally displaced winding parts.

In a preferred embodiment, this directional component is increasing in that the slot is curved in the transverse direction. This contributes to effectively utilize the outwardly increasing volume which may be utilized between the core material.

The optimal situation in this connection is that each slot in its entirety is curved and that all slots have the same direction of curvature, which thus constitutes an additional preferred embodiment of the invention. An ideal design, from the aspect of volume utilization, is then that all the slots are parallel.

The invention may be realized either by designing it with slots with a radially outwardly increasing width, or with slots with a constant width. In both cases, the slots may advantageously be of the "bicycle chain" type, that is, with alternating wide and narrower parts.

According to a preferred embodiment, the conductor, which comprises the means enclosing the electric field, is flexible during at least one full winding turn, which makes possible an advantageous winding process from the point of view of manufacturing engineering.

According to a preferred embodiment, the means enclosing the electric field comprises an inner semiconducting layer surrounding the conductor, an insulating layer surrounding the inner semiconducting layer, and an outer semiconducting layer surrounding the insulating layer.

In an especially preferred embodiment, the layers adhere to one another and have substantially the same coefficient of thermal expansion, whereby it is ensured in an appropriate way that the layers maintain their function when being subjected to the mechanical and thermal stresses occurring during operation.

The above-mentioned and other advantageous embodiments of the invented machine are described in the dependent claims referring to claim 1.

The invention will be described in greater detail by the following detailed description of preferred embodiments thereof with reference to the accompanying drawings.

Figure 1 is a schematic view of a stator in an electric machine according to conventional technique;

Figure 2 is a schematic radial section of a stator according to a preferred embodiment of the invention;

Figures 2a, 2b and 3 - 6 show examples of slot shapes, to which the invention is applicable;

Figure 7 is a principle sketch explaining the inventive concept; and

Figure 8 is a radial section through a conductor in the winding according to the invention.

Figure 1 shows a principle sketch of how the stator of a conventional electric rotating machine is normally designed. In the core 101 of laminated sheet iron, slots 102 are provided for the windings in the stator. Between each pair of slots, a portion 104 with a trapezoidal cross section is formed, in the following referred to as a stator tooth. The distance d_0 between two slots 102 inside the inner lateral area 103 of the stator is determined by the amount of core material which is required for the magnetic flux density which occurs. With completely radial slots with a constant slot width, as in the figure, the width of the intermediate stator tooth will increase outwardly and provide a surplus of core material. The shaded portion of the tooth denotes the core material which thus becomes "unnecessary",

whereas the necessary core material is located between the two dashed lines. The reasoning in this context is to be regarded as a fundamental representation where, in case of different practical applications, modifications from the fundamental representation appear in dependence on different embodiments of the stator of the machine, but where the fundamental aspect of the "usefulness" of the core material is still relevant to a greater or smaller extent. The basic concept of the invention is to eliminate the "unnecessary" core material in various ways, such that the weight and volume of the core may be reduced.

Figure 2 shows a first preferred embodiment of a fundamental design of a stator according to the inventive concept, in which the core 1 is a stator 1 surrounding a rotor (not shown). In the core 1, slots 2 for the windings are provided. The slots 2 are continuously curved, all the slots 2 being curved in the same direction and being parallel. Between each pair of slots 2, a curved tooth 4 is formed with the same principal shape as the slots. Each curved tooth has a width d, that is, the distance between the walls of adjacent slots which is substantially constant and equal to its width d_0 at the inner lateral area 3 of the stator.

The slots are of a so-called bicycle-chain type, in which wide portions alternate with web portions, wherein each of the wider portions accommodates its own cable part. When indicating that the tooth width d is substantially constant, the minor variations, which occur because of these alternating wide portions and web portions, are thus disregarded.

The spiral shape of the slots 2 makes their radial extent smaller than if they had been completely radial with the same number of cable parts in the slots. The shaded field 102 shows the length of the slots in a corresponding radial arrangement of the slots, and (R designates the radial reduction of the stator which could thus be achieved. This makes the stator both smaller and lighter.

Although Figure 2 illustrates a stator according to the invention, where its principles are utilized optimally, there are many alternative possibilities of realizing them. Other considerations during manufacture, design and operation of the machine may lead to embodiments in which the inventive concept is realized in various modified forms and with various degrees of compromise between conflicting considerations.

Figures 2a and 2b illustrate some alternatives for arranging the slots. The circles represent the winding parts. In Fig. 2a, the cable diameter increases outwardly. This is also the case in Fig. 2b, where the slots are extending in a meandering pattern.

In other embodiments, each slot may be curved for part of its extent only, be curved with a changing radius of curvature, or be curved in different directions in meander shape. One slot may also be non-curved with a completely or partially angled relation to the radial direction. Nor does the distance between two slots need to be constant.

Further, Figures 3 to 6 show a few examples of basic shapes of slots, to all of which the invention may be applied. The slots are shown in their basic shape, that is, not curved as in the invention. The slot 2a in Figure 3 has a constant slot width for cable parts where these have the same diameter. The slot 2b in Figure 4 has an outwardly increasing slot width for a winding with coarser winding parts at the farther end. The slots 2c and 2d in Figures 5 and 6, respectively, show corresponding slots of the "bicycle-chain" type, that is, with alternating wide portions and web portions, the function of the latter being to fix the winding parts radially. The slots may also be designed tapering in the outward direction.

Figure 7 schematically shows two adjacently positioned winding parts displaced according to the invention, and where the intention is to show the principle of the invention.

In Figure 7, two winding parts 5, 6 are arranged in a slot 2 in a stator according to the invention. The arrow A designates the radial direction of the stator, and numeral 106 marks how the outer of the winding parts, 6, would be located if it were located completely radially outside the inner winding part 5 in a slot 102, that is, in conventional manner. For the sake of clarity, the winding parts are shown to be tangent to each other, which, of course, is not always the case. However, the representation is, in principle, relevant also when this is not the case.

The outer winding part 6 is displaced across the radial direction by a distance a compared to the conventionally placed winding part 106. This displacement has allowed space to displace the winding part 6 also in the radial direction by a distance b compared to the conventionally placed winding part 106.

With the radii r_1 and r_2 of the two winding parts, distance $b = r_1 + r_2 - \sqrt{(r_1 + r_2)^2 - a^2}$ and if $r_1 = r_2 = r$, this is simplified to $b = 2r - \sqrt{4r^2 - a^2}$. If the lateral displacement $a = r$, the radial displacement $b = r(2 - \sqrt{3}) = 0.27\ r$, that is, it means in this case a reduction of the radial space, required by the outer winding part, by about 14 %.

Finally, Figure 8 shows a cross section of a cable which is particularly suitable for use as a winding in the stator according to the invention. The cable 6 comprises at least one current-carrying conductor 31 of, for example, copper surrounded by a first semiconducting layer 32. Around this first semiconducting layer there is arranged an insulating layer 33, for example an XLPE insulation, and around this layer there is arranged, in turn, a second semiconducting layer 34. The electric conductor may consist of a number of parts 31. The three layers are designed so as to adhere to one another also when the cable is bent. The cable shown is flexible and this property is maintained in the cable during its service life. The illustrated cable also differs from a conventional high-voltage cable in that the outer mechanically protecting casing and the metal screen which normally surrounds it are eliminated.